US010943805B2

(12) United States Patent
Hudgens et al.

(10) Patent No.: US 10,943,805 B2
(45) Date of Patent: Mar. 9, 2021

(54) **MULTI-BLADE ROBOT APPARATUS, ELECTRONIC DEVICE MANUFACTURING APPARATUS, AND METHODS ADAPTED TO TRANSPORT MULTIPLE SUBSTRATES IN ELECTRONIC DEVICE MANUFACTURING**

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Jeffrey C. Hudgens**, San Francisco, CA (US); **Michael R. Rice**, Pleasanton, CA (US); **Karuppasamy Muthukamatchi**, Madurai (IN); **Nir Merry**, Mountain View, CA (US)

(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 135 days.

(21) Appl. No.: **15/983,834**

(22) Filed: **May 18, 2018**

(65) **Prior Publication Data**

US 2019/0355603 A1 Nov. 21, 2019

(51) **Int. Cl.**

H01L 21/677 (2006.01)
H01L 21/687 (2006.01)
H01L 21/67 (2006.01)

(52) **U.S. Cl.**

CPC .. ***H01L 21/67742*** (2013.01); ***H01L 21/67167*** (2013.01); ***H01L 21/68707*** (2013.01)

(58) **Field of Classification Search**

CPC H01L 21/67742; H01L 21/67167; H01L 21/68707; H01L 21/67748; H01L 21/68771; H01L 21/67739; H01L 21/67754; B25J 9/042; B25J 9/104; B25J 9/043; B25J 9/044; B25J 9/006; B25J 9/106; B25J 9/146; B25J 15/0052

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,447,409 A 9/1995 Grunes et al.
5,590,996 A 1/1997 Thompson et al.
5,647,724 A 7/1997 Davis, Jr. et al.

(Continued)

OTHER PUBLICATIONS

Paul Z. Wirth, U.S. Appl. No. 15/708,806 (25481), titled: "Dual-Blade Robot Including Vertically Offset Horizontally Overlapping Frog-Leg Linkages and Systems and Methods Including Same," filed Sep. 19, 2017.

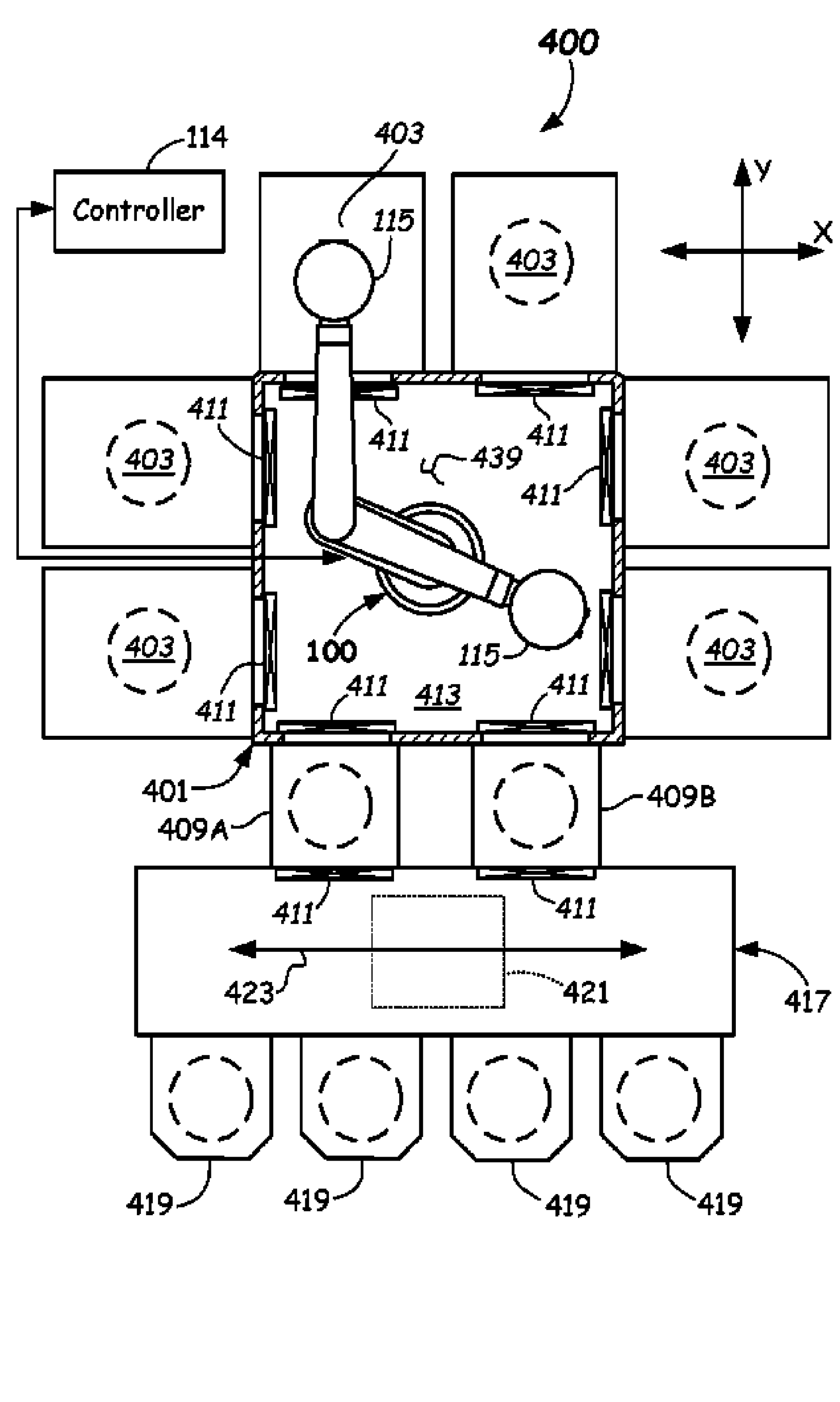
(Continued)

Primary Examiner — Glenn F Myers
(74) *Attorney, Agent, or Firm* — Lowenstein Sandler LLP

(57) **ABSTRACT**

Electronic device manufacturing apparatus and robot apparatus are described. The apparatus are configured to efficiently pick and place substrates wherein the robot apparatus includes an upper arm and three blades B**1**, B**2**, B**3** that are independently rotatable. The three blades are configured to service a first dual load lock and second dual load lock wherein each dual load lock includes a different pitch. In some embodiments, a first pitch P**1** is smaller than a second pitch P**2**. Blades B**2** and B**3** (or optionally blades B**1** and B**2**) can service the first dual load lock with Pitch P**1** and blades B**1** and B**3** can service the second dual load lock including the second pitch P**2**. Methods of operating the electronic device manufacturing apparatus and the robot apparatus are provided, as are numerous other aspects.

21 Claims, 9 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,746,565 A 5/1998 Tepolt
5,789,878 A 8/1998 Kroeker et al.
6,048,162 A 4/2000 Moslehi
6,056,504 A 5/2000 Hudgens et al.
6,132,165 A 10/2000 Carducci
6,155,131 A 12/2000 Suwa et al.
6,669,434 B2 12/2003 Namba et al.
6,722,834 B1 4/2004 Tepman
6,749,391 B2 6/2004 Woodruff et al.
7,136,147 B2 11/2006 Kuit
7,688,017 B2 3/2010 Hudgens
7,927,062 B2 4/2011 Rice et al.
8,016,542 B2 9/2011 Cox et al.
8,061,232 B2 11/2011 Kroetz et al.
8,264,187 B2 9/2012 Laceky et al.
8,692,500 B2 4/2014 Laceky et al.
8,777,547 B2 7/2014 Kremerman et al.
8,784,033 B2 7/2014 Kremerman et al.
9,076,829 B2 * 7/2015 Brodine H01L 21/67742
9,761,478 B2 9/2017 Caveney et al.
2003/0011338 A1 * 1/2003 Gilchrist B25J 9/042
318/568.21
2006/0130751 A1 6/2006 Volfovski et al.
2008/0008569 A1 * 1/2008 Seol H01L 21/67742
414/287
2008/0260500 A1 * 10/2008 Meulen B65G 25/02
414/217
2011/0076117 A1 * 3/2011 Iizuka H01L 21/6719
414/217
2013/0115028 A1 5/2013 Kremerman et al.
2013/0149076 A1 6/2013 Cox et al.
2013/0272823 A1 10/2013 Hudgens et al.
2014/0010625 A1 1/2014 Hudgens et al.
2014/0107825 A1 * 4/2014 Kubodera G05B 19/4189
700/112
2014/0150592 A1 6/2014 Kremerman
2014/0154038 A1 6/2014 Hudgens et al.
2014/0271055 A1 9/2014 Weaver et al.
2014/0286736 A1 9/2014 Kremerman et al.
2014/0286741 A1 9/2014 Kremerman et al.
2015/0013910 A1 1/2015 Krupyshev et al.
2015/0190933 A1 * 7/2015 Kremerman B25J 17/02
414/806
2015/0217446 A1 8/2015 Kremerman
2015/0217466 A1 8/2015 Leicht et al.
2016/0082599 A1 3/2016 Wakabayashi
2016/0107317 A1 4/2016 Hashimoto et al.
2016/0263742 A1 9/2016 Hosek et al.
2016/0284578 A1 9/2016 Weaver et al.
2016/0303742 A1 10/2016 Embertson et al.
2016/0329234 A1 11/2016 Krupyshev et al.
2017/0040203 A1 2/2017 Caveney et al.
2017/0117171 A1 4/2017 Wirth
2017/0368680 A1 12/2017 Muthukamatchi et al.
2019/0088530 A1 3/2019 Wirth

OTHER PUBLICATIONS

PCT International Search Report and Written Opinion for International Application No. PCT/US2019/032980, dated Sep. 18, 2019, 13 pages.

* cited by examiner

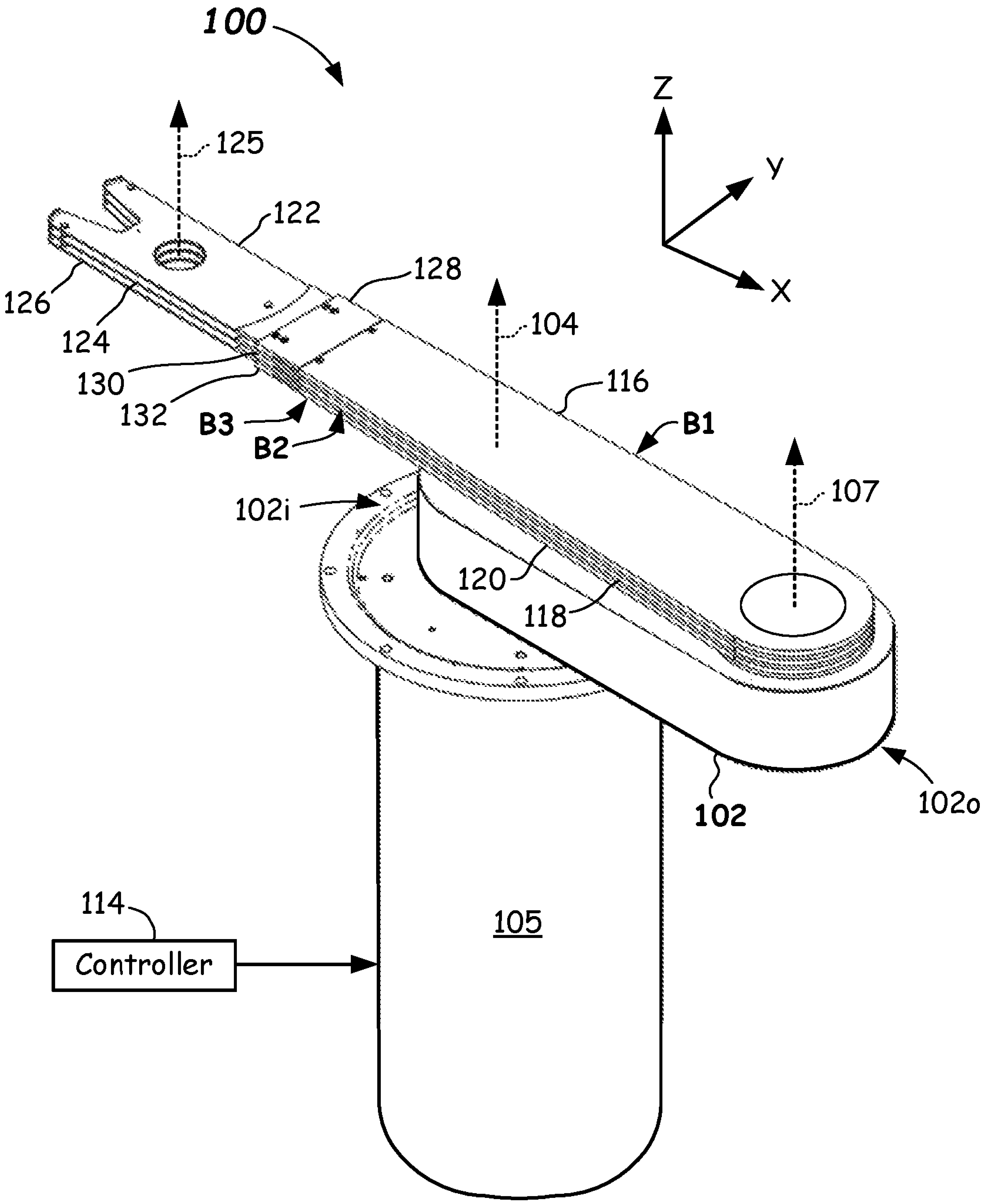

100
125
122
128
126
124
130
132
B3
B2
104
116
B1
Z
y
X
107
102i
120
118
102
102o
114
Controller
105

FIG. 1A

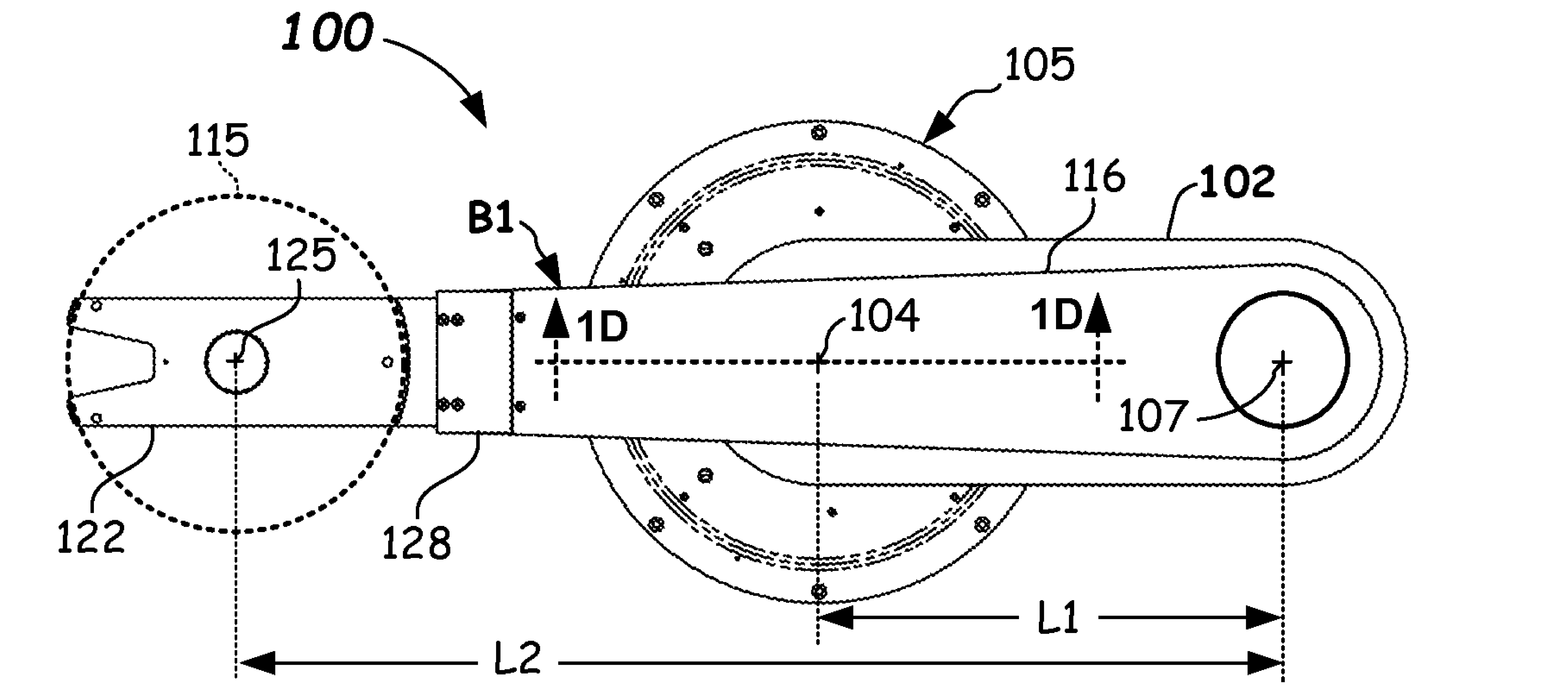

100
105
115
116
102
B1
125
1D
104
1D
107
122
128
L1
L2

FIG. 1B

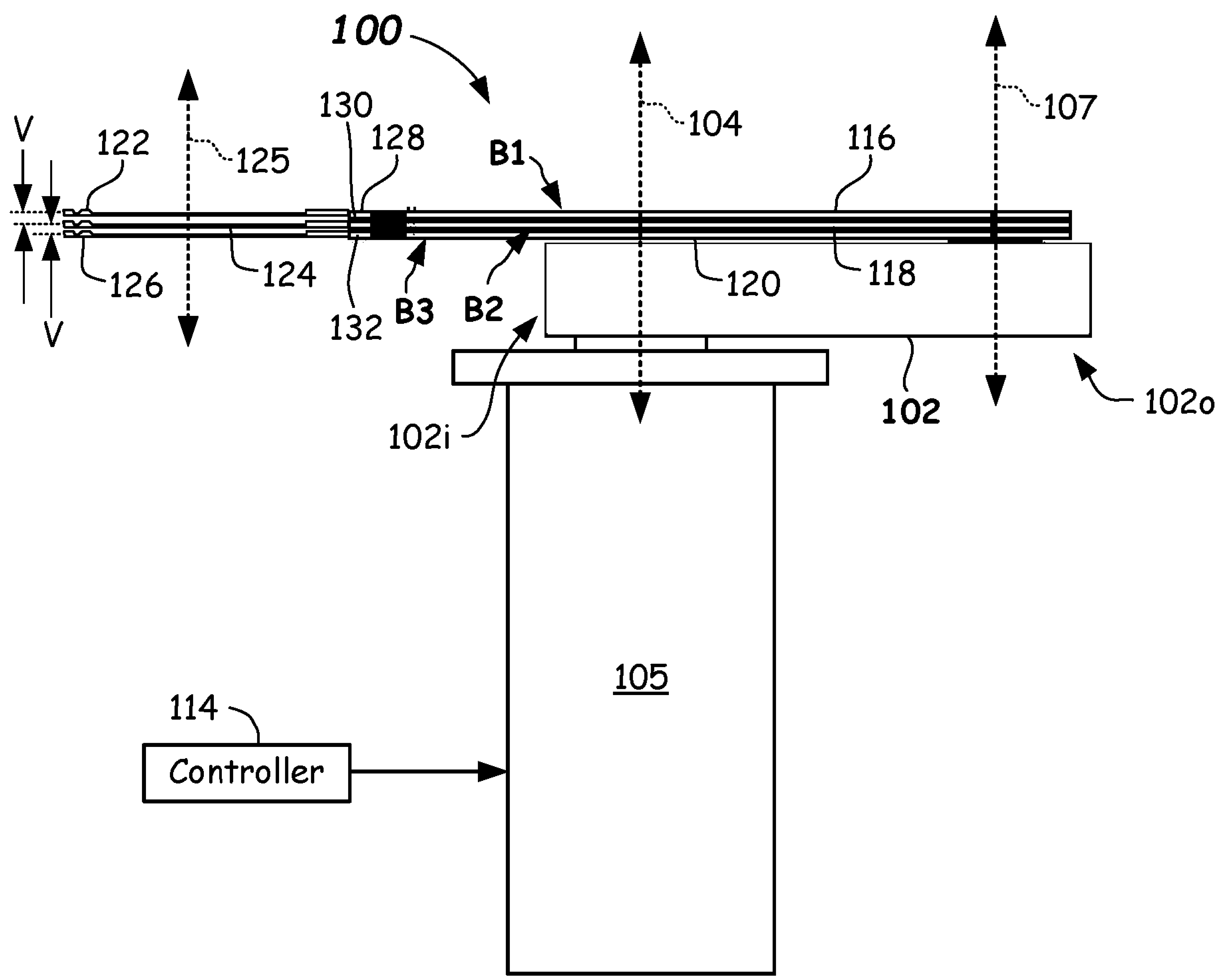

100
130
128
V
122
125
B1
104
116
107
126
124
132
B3
B2
120
118
102i
102
102o
V
105
114
Controller

FIG. 1C

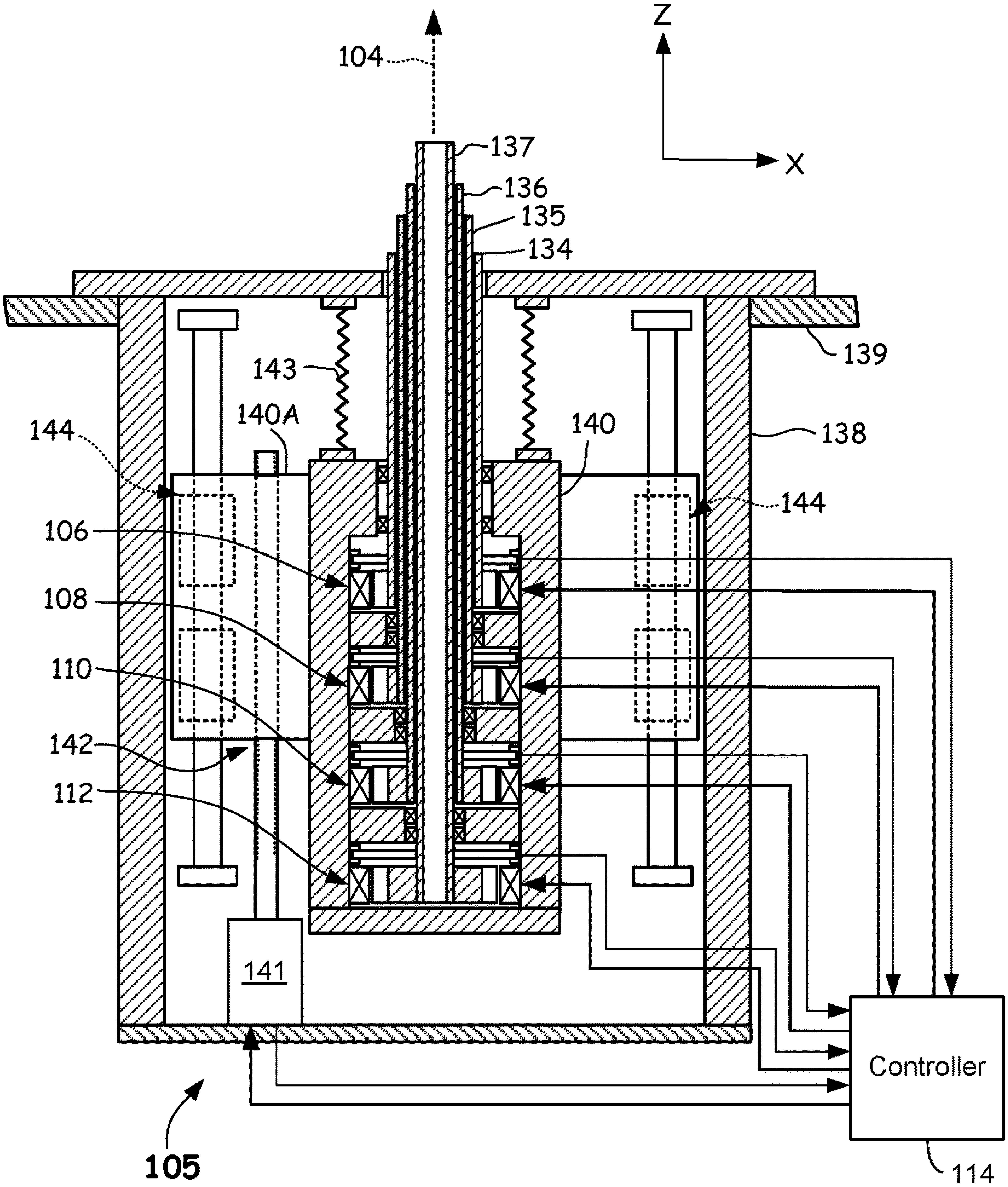

104
Z
X
137
136
135
134
139
143
140A
144
140
138
144
106
108
110
142
112
141
Controller
105
114

FIG. 1D

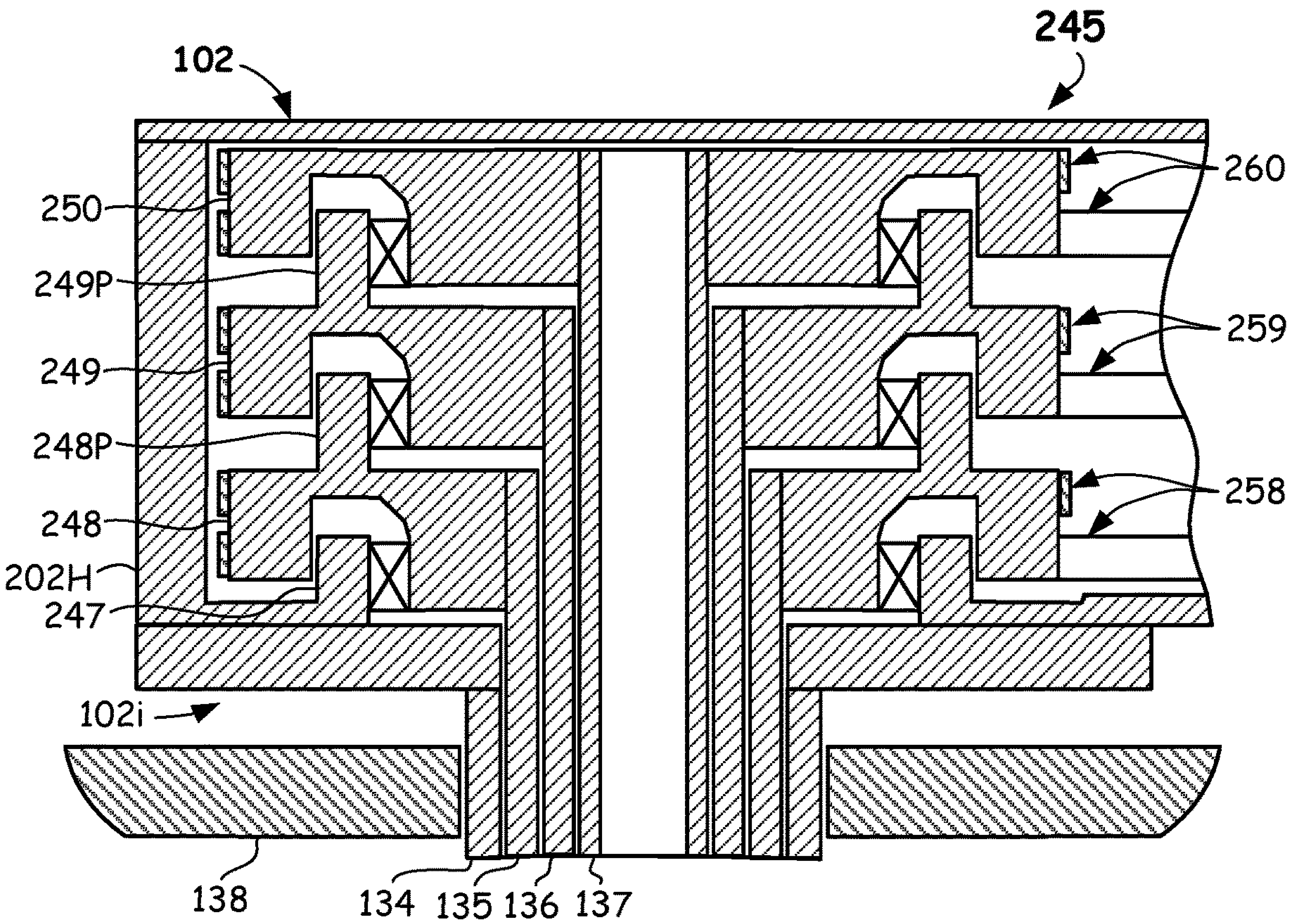

245
102
260
250
249P
259
249
248P
258
248
202H
247
102i
138
134
135
136
137

FIG. 2A

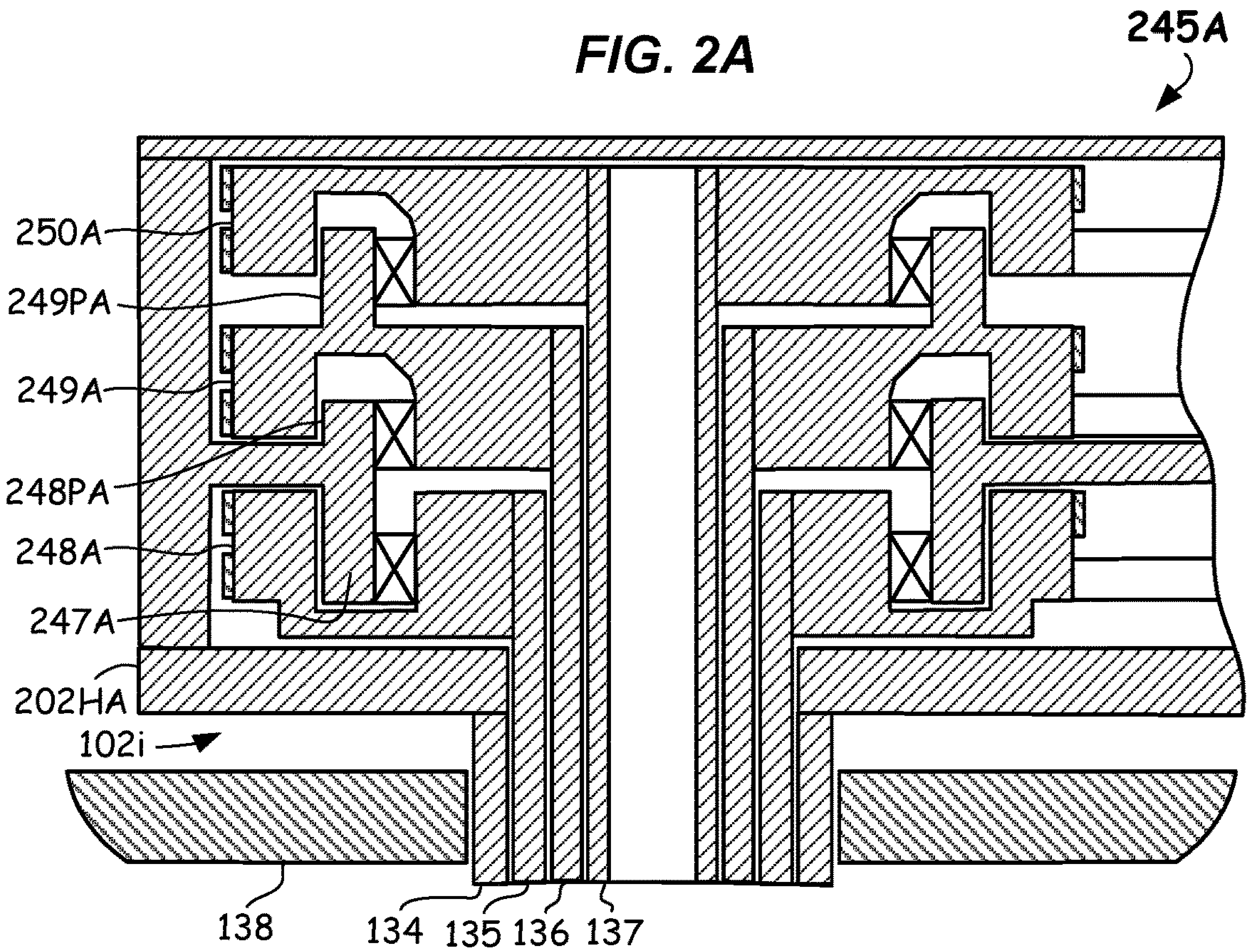

245A
250A
249PA
249A
248PA
248A
247A
202HA
102i
138
134
135
136
137

FIG. 2B

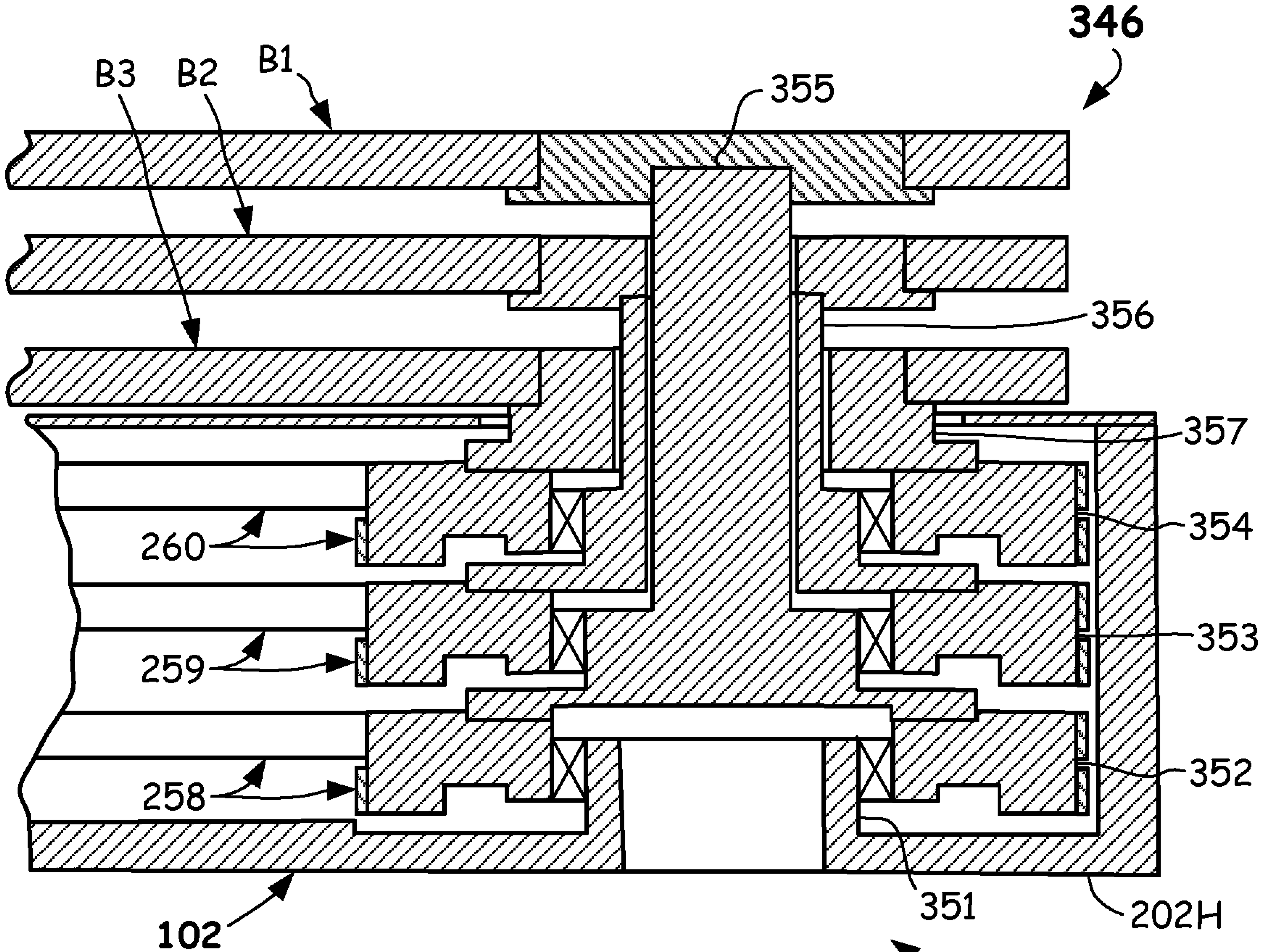

346
B3
B2
B1
355
356
357
260
354
259
353
258
352
102
351
202H
102o

FIG. 3A

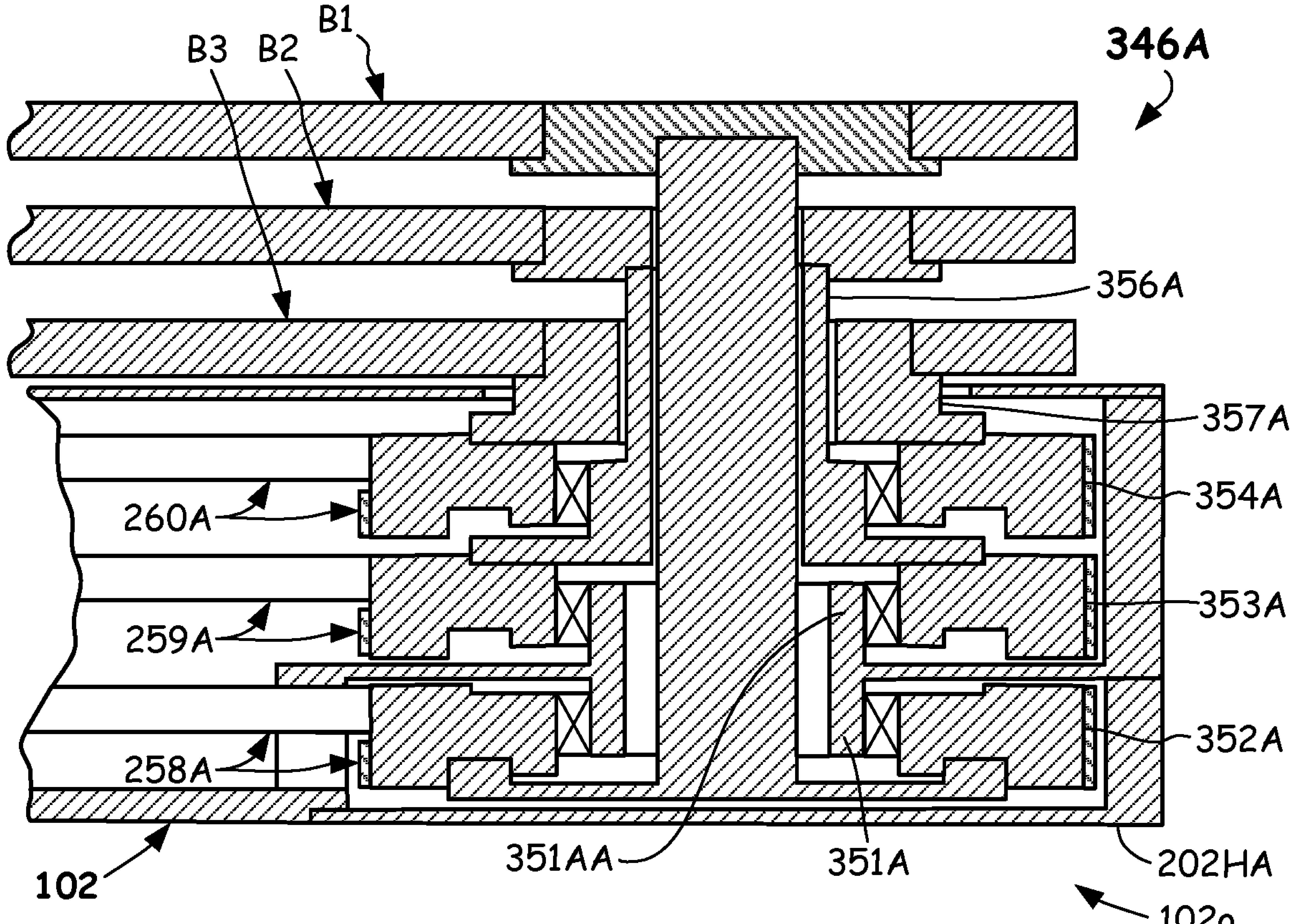

346A
B3
B2
B1
356A
357A
260A
354A
259A
353A
258A
352A
102
351AA
351A
202HA
102o

FIG. 3B

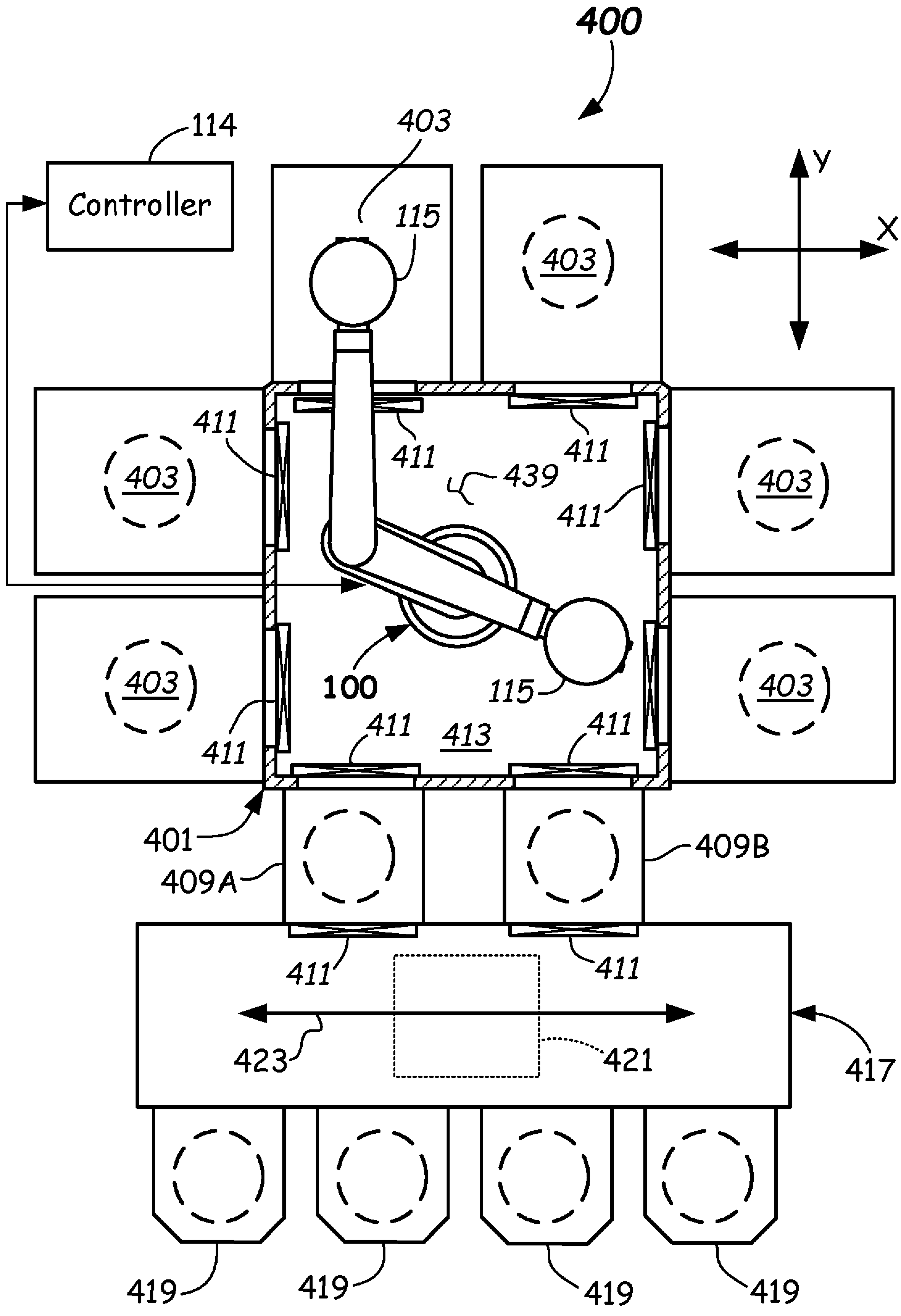

400
114
Controller
403
115
403
Y
X
411
403
411
439
411
411
403
100
115
403
403
411
411
413
411
401
409A
409B
411
411
423
421
417
419
419
419
419

FIG. 4

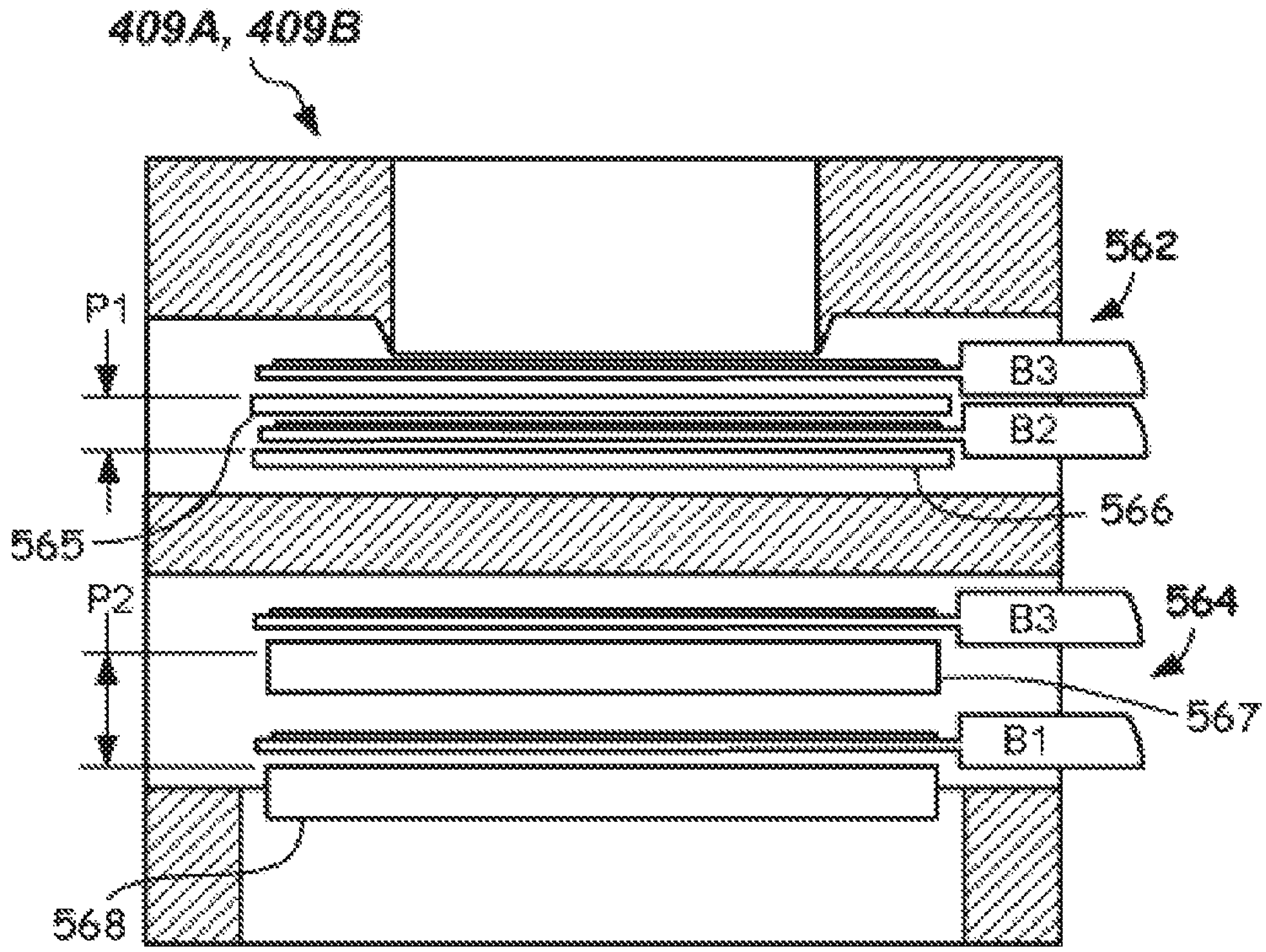

409A, 409B
562
P1
B3
B2
566
565
P2
B3
564
567
B1
568

FIG. 5A

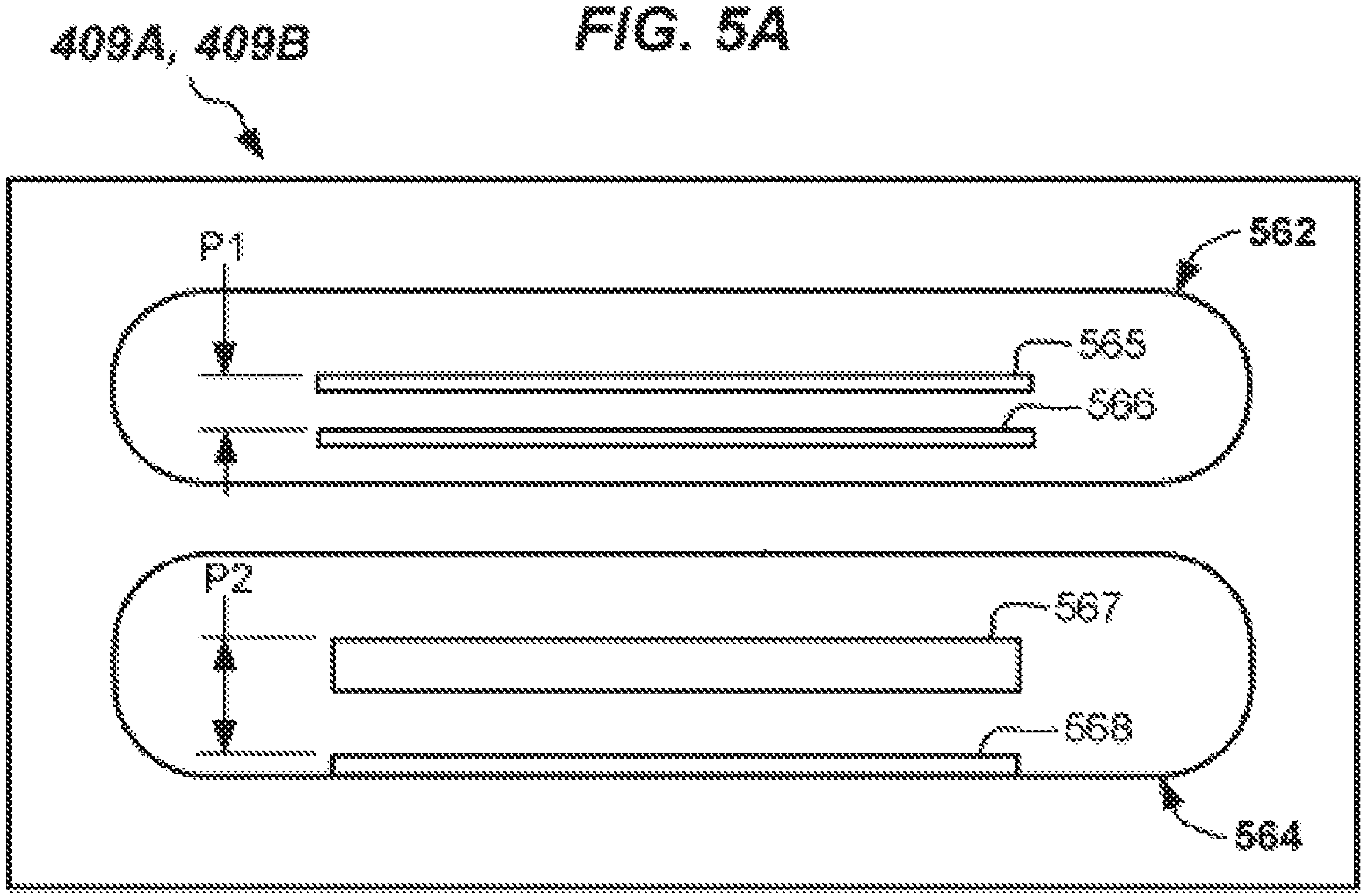

409A, 409B
562
P1
565
566
P2
567
568
564

FIG. 5B

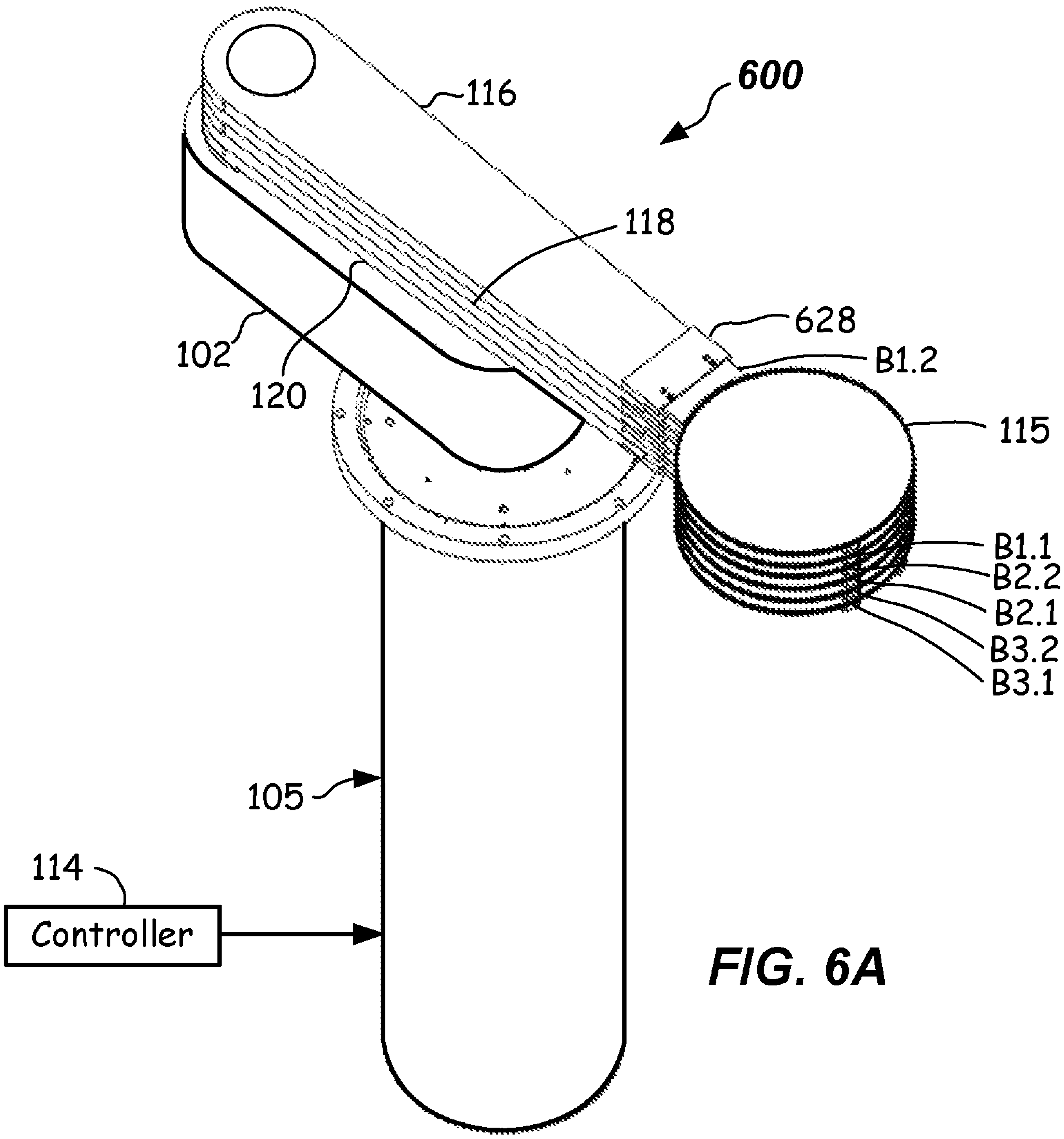

600
116
118
628
B1.2
102
120
115
B1.1
B2.2
B2.1
B3.2
B3.1
105
114
Controller

FIG. 6A

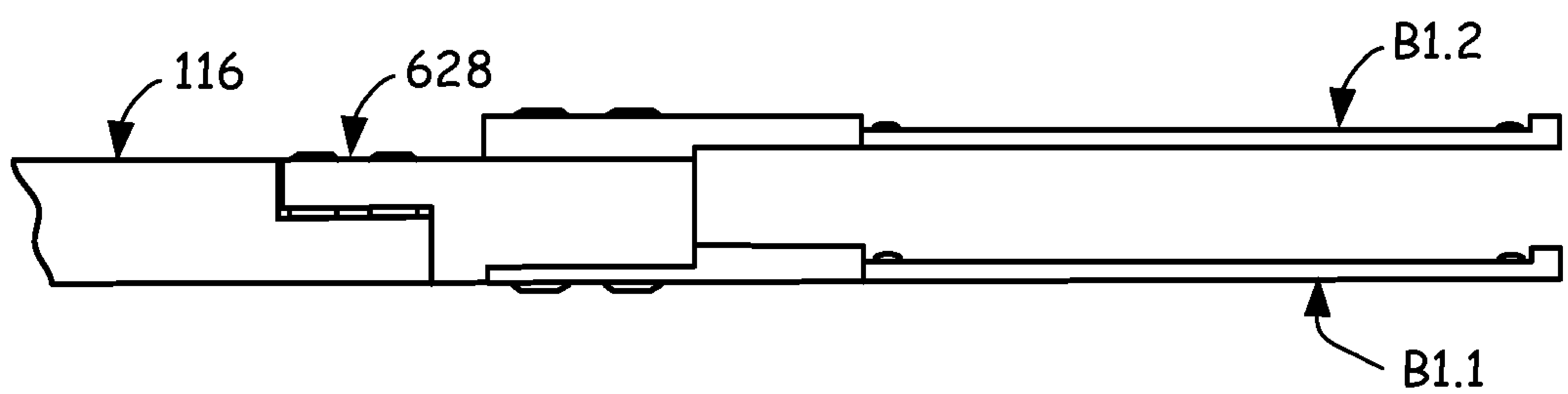

116
628
B1.2
B1.1

FIG. 6B

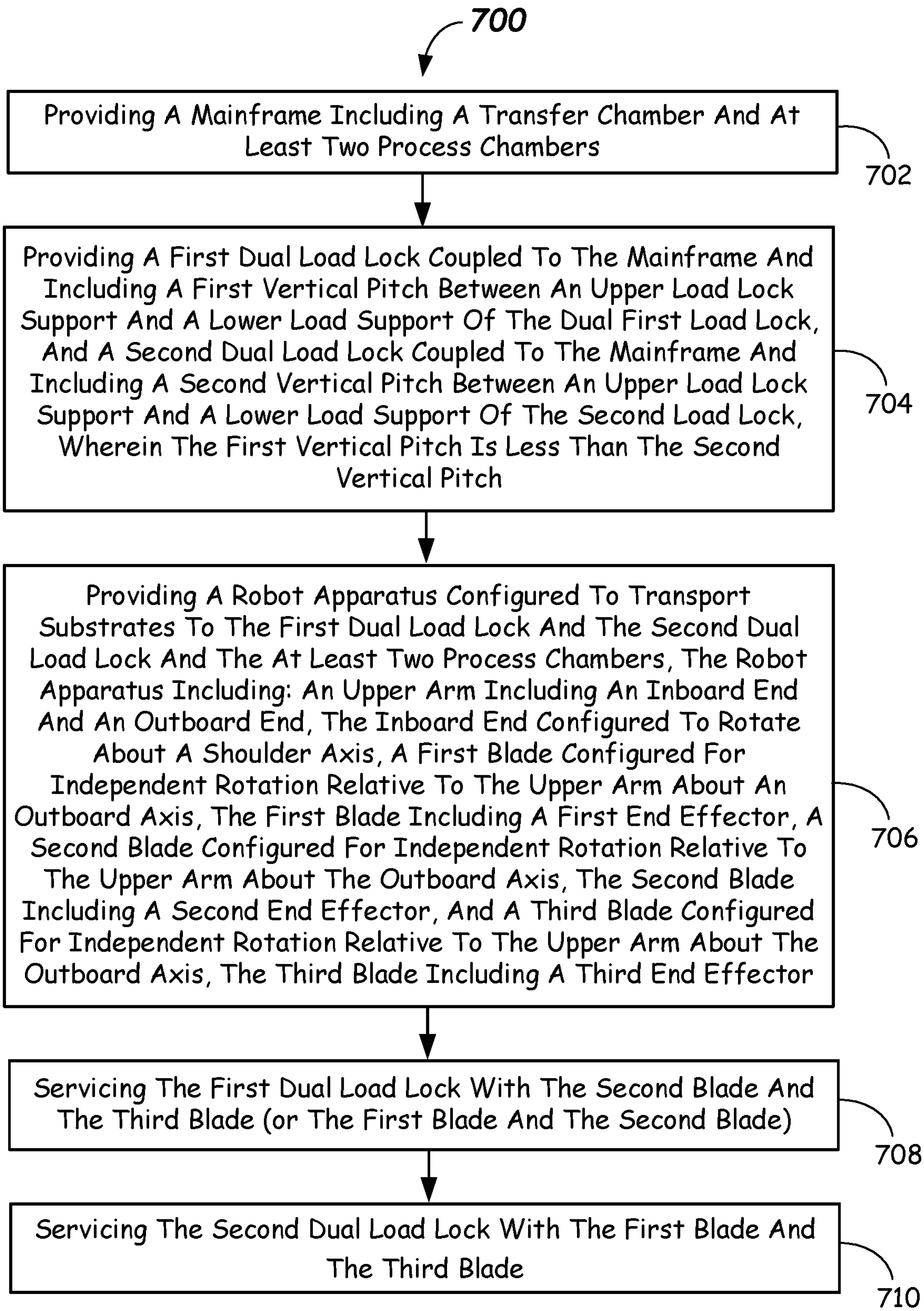

700
Providing A Mainframe Including A Transfer Chamber And At Least Two Process Chambers
702
Providing A First Dual Load Lock Coupled To The Mainframe And Including A First Vertical Pitch Between An Upper Load Lock Support And A Lower Load Support Of The Dual First Load Lock, And A Second Dual Load Lock Coupled To The Mainframe And Including A Second Vertical Pitch Between An Upper Load Lock Support And A Lower Load Support Of The Second Load Lock, Wherein The First Vertical Pitch Is Less Than The Second Vertical Pitch
704
Providing A Robot Apparatus Configured To Transport Substrates To The First Dual Load Lock And The Second Dual Load Lock And The At Least Two Process Chambers, The Robot Apparatus Including: An Upper Arm Including An Inboard End And An Outboard End, The Inboard End Configured To Rotate About A Shoulder Axis, A First Blade Configured For Independent Rotation Relative To The Upper Arm About An Outboard Axis, The First Blade Including A First End Effector, A Second Blade Configured For Independent Rotation Relative To The Upper Arm About The Outboard Axis, The Second Blade Including A Second End Effector, And A Third Blade Configured For Independent Rotation Relative To The Upper Arm About The Outboard Axis, The Third Blade Including A Third End Effector
706
Servicing The First Dual Load Lock With The Second Blade And The Third Blade (or The First Blade And The Second Blade)
708
Servicing The Second Dual Load Lock With The First Blade And The Third Blade
710

FIG. 7

MULTI-BLADE ROBOT APPARATUS, ELECTRONIC DEVICE MANUFACTURING APPARATUS, AND METHODS ADAPTED TO TRANSPORT MULTIPLE SUBSTRATES IN ELECTRONIC DEVICE MANUFACTURING

FIELD

The present disclosure relates to electronic device manufacturing, and more specifically to apparatus and methods adapted to transport multiple substrates within an electronic device manufacturing apparatus.

BACKGROUND

Conventional electronic device manufacturing apparatus can include multiple chambers, such as process chambers and load lock chambers. Such chambers can be included in a cluster tool where a plurality of such process and load lock chambers can be distributed about a transfer chamber. Such electronic device manufacturing apparatus can employ a robot apparatus in the transfer chamber that is configured to transport substrates between the various load lock and process chambers. In some embodiments, the transfer chamber, process chambers, and load lock chambers may operate under a vacuum at certain times. However, in certain configurations of prior art electronic device manufacturing apparatus, transport of substrates between the various chambers with the robot apparatus can be somewhat inefficient.

Accordingly, improved robot apparatus, electronic device manufacturing apparatus, and methods for transporting substrates having improved efficiency are sought.

SUMMARY

In a first aspect a robot apparatus is provided. The robot apparatus includes an upper arm including an inboard end and an outboard end, the inboard end configured to rotate about a shoulder axis, a first blade configured for independent rotation relative to the upper arm about an outboard axis, the first blade including a first end effector, a second blade configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector, and a third blade configured for independent rotation relative to the upper arm about the outboard axis, the third blade including a third end effector.

According to another aspect an electronic device processing system is provided. The electronic device processing apparatus includes a mainframe including a transfer chamber and at least two process chambers, a first dual load lock coupled to the mainframe and including a first vertical pitch between an upper load lock support and a lower load lock support, a second dual load lock coupled to the mainframe and including a second vertical pitch between an upper load lock support and a lower load lock support of the second dual load lock, wherein the first vertical pitch is less than the second vertical pitch, and a robot apparatus configured to transport substrates to the first dual load lock and the second dual load lock and the at least two process chambers, the robot apparatus including: an upper arm including an inboard end and an outboard end, the inboard end configured to rotate about a shoulder axis, a first blade configured for independent rotation relative to the upper arm about an outboard axis, the first blade including a first end effector, a second blade configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector, and a third blade configured for independent rotation relative to the upper arm about the outboard axis, the third blade including a third end effector, wherein a vertical spacing between the first end effector and the second end effector equals the first vertical pitch and a spacing between the first end effector the third end effector is equal to the second vertical pitch.

In another aspect, a method of transporting multiple substrates within an electronic device manufacturing apparatus is provided. The method comprises providing a mainframe including a transfer chamber and at least two process chambers; providing a first dual load lock coupled to the mainframe and including a first vertical pitch between an upper load lock support and a lower load lock support of the dual first load lock, and a second dual load lock coupled to the mainframe and including a second vertical pitch between an upper load lock support and a lower load lock support of the second dual load lock, wherein the first vertical pitch is less than the second vertical pitch; providing a robot apparatus configured to transport substrates to the first dual load lock and the second dual load lock and the at least two process chambers, the robot apparatus including: an upper arm including an inboard end and an outboard end, the inboard end configured to rotate about a shoulder axis, a first blade configured for independent rotation relative to the upper arm about an outboard axis, the first blade including a first end effector, a second blade configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector, and a third blade configured for independent rotation relative to the upper arm about the outboard axis, the third blade including a third end effector; servicing the first dual load lock with the second blade and the third blade (or the first blade and the second blade); and servicing the second dual load lock with the first blade and the third blade.

Numerous other features are provided in accordance with these and other aspects of the disclosure. Other features and aspects of the present disclosure will become more fully apparent from the following detailed description, the claims, and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a perspective view of a robot apparatus including three independently-controllable blades according to one or more embodiments.

FIG. **1**B illustrates a top plan view of a robot apparatus including three independently-controllable blades shown in a folded and zeroed orientation according to one or more embodiments.

FIG. **1**C illustrates a side plan view of a robot apparatus including three independently-controllable bladed shown in a folded and zeroed orientation according to one or more embodiments.

FIG. **1**D illustrates a partially cross-sectioned side plan view showing a drive motor assembly of a robot apparatus according to one or more embodiments.

FIG. **2**A illustrates a partial cross-sectional side view of an inboard end of a drive assembly of a robot apparatus according to one or more embodiments.

FIG. **2**B illustrates a partial cross-sectional side view of an inboard end of an alternative drive assembly of a robot apparatus according to one or more embodiments.

FIG. **3**A illustrates a partial cross-sectional side view of an outboard end of a drive assembly of a robot apparatus according to one or more embodiments.

FIG. 3B illustrates a partial cross-sectional side view of an outboard end of an alternative drive assembly of a robot apparatus according to one or more embodiments.

FIG. 4 is a top schematic view of a robot apparatus shown servicing a process chamber of an electronic device manufacturing apparatus according to one or more embodiments.

FIG. 5A is a partial cross-sectional side view of a load lock apparatus including multiple dual load lock apparatus with different vertical pitches between respective upper and lower substrate supports according to one or more embodiments.

FIG. 5B is a front view of a load lock apparatus of FIG. 5A according to one or more embodiments.

FIG. 6A illustrates a perspective view of an alternative robot apparatus including three independently-controllable wrists and six blades (two end effectors per wrist member) according to one or more embodiments.

FIG. 6B illustrates a partial side view of a blade of the alternative robot apparatus of FIG. 6A showing the attachment features of the dual end effectors according to one or more embodiments.

FIG. 7 is a flowchart depicting a method of transporting multiple substrates within an electronic device manufacturing apparatus according to one or more embodiments.

DETAILED DESCRIPTION

Precision and efficiency of transport of substrates between various locations in electronic device transport systems is sought. However, in some systems, transfer between the various chambers may become a bottleneck limiting efficiency. Furthermore, simplified robot construction is also sought, wherein the number of robotic arms can be minimized.

In order to improve efficiency, many robot apparatus for electronic device manufacturing apparatus include dual end effectors, sometimes referred to as including "dual blades," that may be attached at an end arm of a series of interconnected arms of a robot apparatus and may be adapted to transport multiple substrates resting upon the end effectors to and from process chambers and/or load lock chambers of the electronic device manufacturing apparatus. Conventional dual-blade robot apparatus may only exchange one-for-one. That is, they can retrieve one substrate from a chamber and replace it with one substrate. Accordingly, robot apparatus and electronic device apparatus that include improved handoff efficiencies would constitute a substantial advancement in the electronic device manufacturing art.

Therefore, embodiments of the present disclosure, in one aspect, provide a robot apparatus having a compact configuration and including three blades (B**1**, B**2**, B**3**), wherein each blade is independently controllable. A blade as used herein means a combination of a wrist member and at least one end effector, either as separate components or as one integral component. Robot apparatus embodiments described herein include an upper arm, and multiple blades rotatable about an outboard end of the upper arm. In particular, the wrist members can be rotatable about an outboard end of the upper arm. Thus, a refined robot construction having few arms is provided. The inboard end of the upper arm is rotatable about a shoulder axis. Each of the three blades (B**1**, B**2**, and B**3**) may include attached end effectors, i.e., combinations of a wrist member and an end effector.

The independent control of the respective wrist members and thus blades (B**1**, B**2**, and B**3**) is provided by a drive assembly. The drive assembly includes respective drive shafts coupled or interconnected to drive the upper arm and the first blade B**1**, second blade B**2**, and third blade B**3**, in rotation. Accordingly, all of the moving components (e.g., upper arm and first, second, and third blades) may be driven from a common drive location. This highly functional configuration enables not only a simplified robot construction, but may also allow enhanced efficiency, as will be apparent from the following.

In another aspect, an electronic device manufacturing apparatus is provided that includes a robot apparatus having three independently-controllable blades (B**1**, B**2**, B**3**) including end effectors that may be used for transporting substrates between process chambers and load lock chambers. The electronic device manufacturing apparatus includes a robot apparatus including the upper arm and three coupled independently-controllable blades. The electronic device manufacturing apparatus further includes a first dual load lock and a second dual load lock. The first and second dual load locks have different vertical pitches between respective upper and lower substrates supports provided therein. In one embodiment, one dual load lock includes a vertical pitch of 1 P whereas another dual load lock includes a vertical pitch of greater than 1 P (e.g., 1 P×2=2 P). The larger-pitch dual load lock can be serviced by blade B**1** (upper blade) and blade B**3** (lower blade), whereas the smaller pitch dual load lock can be serviced by blade B**2** (middle blade) and blade B**3** (lower blade). In some embodiments, the robot apparatus can include z-axis capability.

Further details and example embodiments illustrating various aspects of the robot apparatus and electronic device manufacturing apparatus are described with reference to FIGS. **1A-6** herein.

Referring now to FIGS. **1A-1D**, an example embodiment of a robot apparatus **100** configured for use in an electronic device manufacturing apparatus **400** (FIG. **4**) according to embodiments of the present disclosure is provided. The robot apparatus **100** is useful for, and may be configured and adapted to transfer substrates **115** between various process chambers **403**, and/or to exchange substrates **415** at one or more load lock apparatus **409**A, **409**B, for example. In the depicted embodiment, two load lock apparatus **409**A, **409**B. However, the robot apparatus **100** could be used with only one load lock apparatus or more than two load lock apparatus.

The robot apparatus **100** has an upper arm **102** including an inboard end **102*i*** and outboard end **102*o***. The inboard end **102*i*** is configured to be rotatable about a shoulder axis **104** by an upper arm drive motor **106** (FIG. **1**D) of a drive motor assembly **105**. A drive assembly of driving and driven pulleys and transmission members is included within the upper arm **102** as will be apparent from the following.

The robot apparatus **100** shown includes three blades B**1** (upper), B**2** (middle), B**3** (lower) coupled for rotation to the outboard end **102*o*** of the upper arm **102** opposite from the inboard end **102*i***. Each of the blades B**1**, B**2**, B**3** is independently rotatable about the outboard axis **107** through the commanded action of first drive motor **108**, second drive motor **110**, and third drive motor **112**, respectively. Each of the first drive motor **108**, second drive motor **110**, and third drive motor **112** is commanded by a suitable control signal received from a controller **114**. Controller **114** can be any suitable processor, memory, conditioning electronics and drivers capable of processing control instructions and carrying out motion of the upper arm **102** and blades B**1**, B**2**, B**3**.

The upper arm **102** can have a center-to-center length of L**1**, as shown in FIG. **1**B, wherein the centers of the length L**1** are the shoulder axis **104** and the outboard axis **107**. Each of the blades B1, B2, B3 in the depicted embodiment can be made up of a wrist member, namely first wrist member **116**, second wrist member **118**, and third wrist member **120**. Further, each of the blades B1, B2, B3 in the depicted embodiment includes an end effector, namely first end effector **122**, second end effector **124**, and third end effector **126**, that are each configured and adapted to support and transport a substrate **115** thereon.

The blades B1, B2, B3 each have a center-to-center length L2, as shown in FIG. 1B, wherein the centers of the blades B1, B2, and B3 are the outboard axis **104** and a nominal center **125** of a substrate support location that is configured to support substrates **115** on each of end effectors **122**, **124**, **126**. The nominal center **125** is where the substrate **115** will rest on each of the first, second, and third end effectors **122**, **124**, **126** when nominally positioned thereon. Restraining features restrain location of the substrates on the end effectors **122**, **124**, **126** within limits. In the depicted embodiment, the first, second, and third wrist members **116**, **118**, **120** and the end effectors **122**, **124**, **126** are separate interconnected members. However, it should be understood that each wrist member and end effector may be integrally formed in some embodiments and constitute one unitary component. In the depicted embodiment, each of the wrist members **116**, **118**, **120** may include an orientation adjuster **128**, **130**, **132** at the end thereof to allow for fine orientation adjustments (e.g., adjustments for droop and/or tilt) to each of the end effectors **122**, **124**, **126**. The orientation adjusters **128**, **130**, **132** can use screws and/or shims to accomplish end effector attitude adjustments.

Thus, it should be apparent that the first blade B1 is configured for independent rotation relative to the upper arm **102** about the outboard axis **107**, and wherein the first blade B1 includes the first end effector **122**. Likewise, the second blade B2 is configured for independent rotation relative to the upper arm **104** about the outboard axis **107**, and wherein the second blade B2 includes a second end effector **124**. Moreover, the third blade B3 is configured for independent rotation relative to the upper arm **102** about the outboard axis **107**, and wherein the third blade B3 includes the third end effector **126**. The rotation is provided by the drive motor assembly **105** and the drive assembly described below.

As can be seen in FIGS. 1A and 1B, the first end effector **124**, second end effector **126**, and the third end effector **128** lie one above another when configured in a folded and zeroed configuration, as shown. This folded and zeroed configuration is the neutral configuration and the blades B1, B2, B3, can be rotated approximately +/−170 degrees from this orientation, for example.

As can be seen in FIG. 1B, the robot apparatus **100** includes blades B1, B2, B3 that each have a length L2 that is longer than the center-to-center length L1 of the upper arm **102**. In particular, the respective center-to-center lengths L1, L2 are related by $L2 \geq L1$. In some embodiments, $L2 > 2L1$. In other embodiments, the respective center-to center lengths can be related by $L1 \leq L2 \leq 2 \times L1$, or even $1.5 \times L1 \leq L2 \leq 2 \times L1$. By way of example, and not to be considered limiting, L1 can be between about 450 mm and 600 mm and L2 can be between about 450 mm and 1,200 mm. In some embodiments, L1 can be between about 800 mm and 1,000 mm and L2 can be between about 450 mm and 1,200 mm. In some embodiments L2 could be less than L1.

Furthermore, a first vertical spacing between a first support location of the first end effector **122** and a second support location of the second end effector **124** can be the same as a second vertical spacing between the second support location of the second end effector **124** and a third support location of the third end effector **126**, i.e., the blades B1, B2, B3 can be equally vertically spaced. The vertical spacing V (FIG. 1C) between the support locations of the respective end effectors **122**, **124**, **126** can range from 7 mm to 25 mm, from 7 mm to 20 mm, or even between 9 mm and 18 mm, for example. Other vertical spacing values are possible.

Now in more detail and referring to FIG. 1D, the drive motor assembly **105** is described. The connections to the respective upper arm **102** and driving pulleys are not shown in FIG. 1D for clarity. The drive motor assembly **105** includes an upper arm shaft **134** configured to be coupled to the upper arm drive motor **106** on a lower end and configured to couple to and drive the upper arm **102** on an upper end and cause independent rotation thereof in an X-Y plane. The upper arm shaft **134** is coupled to the inboard end **102***i* of the upper arm **102** by any suitable means, such as fasteners or the like.

The drive motor assembly **105** further includes a first blade shaft **135** coupled to the first drive motor **108** on a lower end and configured to interconnect to and drive the first blade B1 and cause independent rotation thereof in an X-Y plane. The drive motor assembly **105** further includes a second blade shaft **136** coupled to the second drive motor **110** on a lower end and configured to interconnect to and drive the second blade B2 and cause independent rotation thereof in an X-Y plane. Finally, the drive motor assembly **105** includes a third blade shaft **137** coupled to the third drive motor **112** on a lower end and configured to interconnect to and drive the third blade B3 and cause independent rotation thereof in an X-Y plane. The shafts **134**, **135**, **136**, **137** may be supported for rotation by suitable rotation-accommodating members, such as bearings. Any suitable bearing may be used, such as sealed ball bearings.

The drive motor assembly **105** may include an outer motor housing **138**, which may be coupled to a floor **139** of a transfer chamber **413** as shown in FIG. 4, for example. An inner motor housing **140** of the drive motor assembly **105** can be fixed in regards to rotation relative to the outer motor housing **138**, but can move in the Z direction to accomplish z-axis motion of the blades B1, B2, B3. Motion along the Z-axis can be accommodated by any suitable linear slide mechanism, such as rails and linear bearings shown, for example. It should be recognized that Z-axis capability may not be present in all embodiments, and is therefore optional.

In embodiments with Z-axis capability, FIG. 1D illustrates a vertical motor **141** and a vertical drive mechanism **142** that is configured and adapted to cause vertical motion (along the Z-axis) of the inner motor housing **140** relative to the outer motor housing **138** and thus vertical motion of the first, second, and third blades B1, B2, B3. The vertical drive mechanism **142** may comprise a worm drive, lead screw, ball screw, or rack and pinion mechanism that, when rotated by the vertical motor **141**, causes the inner motor housing **140** to translate vertically along the plus or minus Z-axis and accomplishing raising or lowering of the blades B1, B2, B3. A vacuum barrier **143** (e.g., a sealed bellows or the like) may be used to accommodate the vertical motion and also act as a vacuum barrier in some embodiments. One or more translation-accommodating devices **144** (shown dotted), such as linear bearings, bushings, or other linear motion-restraining means may be used to restrain the motion of the inner motor housing **140** to vertical motion only along the Z-axis, i.e., along shoulder axis **104**. In the depicted embodiment, a lead screw may engage a lead nut mounted to an appendage **140**A of the inner motor housing **140**. Vertical motor **141** can be a stepper motor or the like.

Vertical motor **141** may include feedback via a rotation or translation to provide vertical position feedback information to the controller **114** in some embodiments. Likewise, any suitable type of feedback device may be provided to determine a precise rotational position of the upper arm **102** and each of the blades B**1**, B**2**, B**3**. For example, encoders may be coupled to the upper arm shaft **134**, first shaft **135**, second shaft **136**, and third shaft **137** and measure rotational position relative to the inner housing **140**. The encoders may be rotary encoders and may be a magnetic type, optical type, or another type of rotary encoder.

The independent rotation of the upper arm **102** in the X-Y plane about the shoulder axis **104** may be provided by connection of the upper arm shaft **134** to the upper arm **102** by any suitable means, such as fasteners or other suitable means. Optionally, the upper arm shaft **134** may be made integral with the upper arm **102**. The upper arm drive motor **106** may be a stepper motor, variable reluctance motor, permanent magnet electric motor, or the like. Other types of motors may be used. The rotation of the upper arm **102** may be independently controlled by suitable commands provided to the upper arm drive motor **106** from the controller **114**. Controller **114** may also receive positional feedback information from the encoder via a wiring harness connected between the upper arm drive motor **106** and the controller **114**. Rotation of the upper arm **102** may be up to about +/−360 degrees or more from the folded and zeroed orientation shown in FIG. **1**B, for example.

Rotation of the first blade B**1** in the X-Y plane about the outboard axis **107** may be provided by action of the first drive motor **108** rotating the first blade shaft **135**. The first drive motor **108** may be the same as discussed above. The rotation of the first blade B**1** may be independently controlled by suitable commands provided to the first drive motor **108** from the controller **114**. Controller **114** may also receive positional feedback information from the encoder, a portion of which is coupled to the first blade shaft **135** via a wiring harness connected between the first drive motor **108** and the controller **114**. Rotation of the first blade B**1** may be up to about +/−170 degrees from the folded and zeroed orientation shown in FIG. **1**B, for example.

Rotation of the second blade B**2** in the X-Y plane about the outboard axis **107** may be provided by action of the second drive motor **110** rotating the second blade shaft **136**. The second drive motor **110** may be the same as discussed above. The rotation of the second blade B**2** may be independently controlled by suitable commands provided to the second drive motor **110** from the controller **114**. Controller **114** may also receive positional feedback information from the encoder, a portion of which is coupled to the second blade shaft **136** via a wiring harness connected between the second drive motor **110** and the controller **114**. Rotation of the second blade B**2** may be up to about +/−170 degrees from the folded and zeroed orientation shown in FIG. **1**B, for example.

Likewise, rotation of the third blade B**3** in the X-Y plane about the outboard axis **107** may be provided by action of the third drive motor **112** rotating the third blade shaft **137**. The third drive motor **112** may be the same as discussed above. The rotation of the third blade B**3** may be independently controlled by suitable commands provided to the third drive motor **112** from the controller **114**. Controller **114** may also receive positional feedback information from the encoder, a portion of which is coupled to the third blade shaft **137** via a wiring harness connected between the third drive motor **112** and the controller **114**. Rotation of the third blade B**3** may be up to about +/−170 degrees from the folded and zeroed orientation shown in FIG. **1**B, for example.

Now referring to FIGS. **2**A and **3**A, a first embodiment of a blade drive assembly including the inboard end drive assembly **245** (FIG. **2**A) and an outboard end drive assembly **346** (FIG. **3**B) is shown and described. The inboard end drive assembly **245** includes a first inboard pilot **247** that can extend upwardly (as shown) from a lower portion of an upper arm housing **202**H, and a first driving pulley **248** mounted for rotation on the first pilot **247**, such as by a suitable bearing or the like. All bearings in inboard end drive assembly **245** and outboard end drive assembly **346** are denoted by X in a box.

Inboard end drive assembly **245** further includes a second driving pulley **249** mounted for rotation on the first driving pulley **248**, such as by a suitable bearing or the like coupled between the second driving pulley **249** and a pilot portion **248**P of the first driving pulley **248**. First driving pulley **248** and second driving pulley **249** can be co-axial as shown. Inboard end drive assembly **245** further includes a third driving pulley **250** mounted for rotation on the second driving pulley **249**, such as by a suitable bearing or the like coupled between the third driving pulley **250** and a pilot portion **249**P of the second driving pulley **249**. Second driving pulley **249** and third driving pulley **250** can be co-axial as shown. Connections between the respective shafts **134-137** and the respective driving pulleys **248**, **249**, **250** can be by any suitable connection mechanism, such as bolts, screws, a clamping mechanism, or the like.

Referring now to FIG. **3**A, the outboard end **102***o* of the blade drive assembly includes outboard end drive assembly **346**. The outboard end drive assembly **346** includes a first outboard pilot **351** that may extend upwardly, as shown, from a bottom portion of the upper arm housing **202**H, and a first driven pulley **352** mounted for rotation on the first outboard pilot **351**, such as by a suitable bearing or the like. Outboard end drive assembly **346** further includes a second driven pulley **353** mounted for rotation on the first driven pulley **352**, such as by bearings or the like. First driven pulley **352** and second driven pulley **353** can be co-axial as shown. Outboard end drive assembly **346** can further include a third driven pulley **354** mounted for rotation on the second driven pulley **353**.

The mounting for rotation in each case may be by mounting the respective driven pulley to a respective shaft connected to a respective blade. For example, rotational connection may be via first outer shaft **355** connecting blade B**1** to first driven pulley **352**, second outer shaft **356** connecting blade B**2** to second driven pulley **353**, and third outer shaft **357** connecting blade B**3** to third outboard driven pulley **354**. Bolts, screws, or other fasteners (not shown) may be used to make the various connections.

Now referring to FIGS. **2**B and **3**B, another embodiment of a blade drive assembly including the inboard end drive assembly **245**A and an outboard end drive assembly **346**A are shown and described. The inboard end drive assembly **245**A includes a first inboard pilot **247**A that can extend downwardly as shown from a central portion of an upper arm housing **202**HA, and a first driving pulley **248**A mounted for rotation on the first pilot **247**A, such as by a suitable bearing or the like. Inboard end drive assembly **245**A further includes a second driving pulley **249**A mounted for rotation on the first driving pulley **248**A, such as by a suitable bearing or the like coupled between the second driving pulley **249**A and a portion **248**PA extending upwardly from the central portion of the upper arm housing **202**HA. Inboard end drive assembly **245**A further includes a third driving pulley **250**A mounted for rotation on the second driving pulley **249**A, such as by a suitable bearing or the like coupled between the third driving pulley **250**A and a portion **249**PA of the second driving pulley **249**A. Connections between the respective shafts **134-137** and the respective driving pulleys **248**A, **249**A, **250**A can be by any suitable connection mechanism, such as bolts, screws, a clamping mechanism, and the like.

Referring now to FIG. **3**B, the outboard end **102***o* of the blade drive assembly includes outboard end drive assembly **346**A. The outboard end drive assembly **346**A includes a first outboard pilot **351**A that may extend downwardly, as shown, from a central portion of the upper arm housing **202**HA, and a first driven pulley **352**A mounted for rotation on the first outboard pilot **351**A, such as by a suitable bearing or the like. Outboard end drive assembly **346**A can further include a second driven pulley **353**A mounted for rotation on a second pilot **351**AA extending upwardly from a central portion of the upper arm housing **202**HA, such as by bearings or the like. Outboard end drive assembly **346**A can further include a third driven pulley **354**A mounted for rotation on the second driven pulley **353**A. The mounting for rotation can be by rotationally mounting the third driven pulley **354**A to a second shaft **356**A connected to a second blade B**2** and the second driven pulley **353**A. Bolts, screws or other fasteners (not shown) may be used to make the various connections between the first shaft **355**A and the first driven pulley **352**A, and the first shaft and the first blade B**1**. Likewise, bolts, screws or other fasteners (not shown) may be used to connect the second shaft **355**A to the second blade B**2** and to the second driven pulley **353**A, and the used to connect the third shaft **357**A to the first blade B**1** and to the third driven pulley **354**A.

In each embodiment above, a transmission member can connect between the respective driving pulleys and driven pulleys of the respective blade drive assemblies. For example, in the embodiment of FIGS. **2**A and **3**A, a first transmission member **258** can interconnect the first driving pulley **248** and the first driven pulley **352**. A second transmission member **259** may interconnect the second driving pulley **249** and the second driven pulley **353**. A third transmission member **260** may interconnect the third driving pulley **250** and the third driven pulley **354**.

Likewise, in the embodiment of FIGS. **2**B and **3**B, a first transmission member **258**A may interconnect the first driving pulley **248**A and the first driven pulley **352**A. A second transmission member **259**A may interconnect the second driving pulley **249**A and the second driven pulley **353**A. A third transmission member **260**A may interconnect the third driving pulley **250**A and the third driven pulley **354**A.

The first, second, and third transmission members **258**, **258**A, **259**, **259**A, **260**, and **260**A may comprise one or more belts or straps, such as two oppositely-wound discontinuous metal straps, wherein each strap is rigidly coupled (e.g., pinned) to the corresponding driving pulley **248**, **248**A, **249**, **249**A, **250** and **259**A and driven pulley **342**, **342**A, **353**, **353**A, **354**, **354**A at the ends thereof.

The robot apparatus **100** is adapted to pick or place substrates **115** (sometimes referred to as “wafers” or “semiconductor wafers”) to or from a destination in an electronic device manufacturing system **400**, as is shown in FIG. **4**. However, any type of electronic device substrate, mask, or other silica-containing substrate may be conveyed and transferred by the robot apparatus **100**. The destination may be one or more chambers coupled to the transfer chamber **413**. For example, the destination may be one or more process chambers **403** and/or one or more of the load lock apparatus

409A, **409**B that may be distributed about and coupled to the transfer chamber **413**. As shown, transfers may be through slit valves **411**, for example.

The electronic device processing system **400** can include a mainframe **401** including the transfer chamber **413** and at least two process chambers **403**. A housing of the mainframe **401** includes the transfer chamber **413** therein. The transfer chamber **413** can include top wall (not shown), bottom wall (floor) **439**, and side walls, and, in some embodiments, may be maintained in a vacuum, for example. In the depicted embodiment, the robot apparatus **100** is mounted to the bottom wall (floor) **439**. However, it could be mounted elsewhere, such as to the top wall (not shown—removed for clarity).

Process chambers **403** may be adapted to carry out any number of processes on the substrates **115**. The processes can include deposition, oxidation, nitration, etching, polishing, cleaning, lithography, metrology, or the like. Other processes may be carried out, as well. The load lock apparatus **409**A, **409**B may be adapted to interface with a factory interface **417** or other system component, that may receive substrates **115** from substrate carriers **419** (e.g., Front Opening Unified Pods (FOUPs)) that can be docked at load ports of the factory interface **417**, for example. A load/unload robot **421** (shown dotted) may be used to transfer substrates **115** between the substrate carriers **419** and the load lock apparatus **409**A, **409**B. Transfers of substrates **115** may be carried out in any sequence or direction. Load/unload robot **421** may be identical to robot apparatus **100** in some embodiments, but may include a mechanism to allow the robot apparatus to move laterally in either lateral direction and indicated by arrow **423**. Any other suitable robot can be used.

Referring now to FIGS. **5**A and **5**B, transfer of substrates **115** through the load lock apparatus **409**A, **409**B and to and from the transfer chamber **413** (FIG. **4**) is described. Load lock apparatus **409**A, **409**B may be identical in some embodiments. In the depicted embodiment, at least one of the load lock apparatus **409**A, **409**B, and preferably both, include a first dual load lock **562** that is coupled or interconnected between the factory interface **417** and the mainframe **401** (FIG. **4**). First dual load lock **562** includes a first vertical pitch P**1** between an upper support surface of an upper load lock support **565** and an upper support surface of a lower load lock support **566** of the first dual load lock **562**. Upper load lock support **565** and lower load lock support **566** can be disc-shaped pedestals, for example. At least one of the load lock apparatus **409**A, **409**B, and preferably both, include second dual load lock **564** that can be coupled to or interconnected between the factory interface **417** and the mainframe **401** (FIG. **4**) and can includes a second vertical pitch P**2** between an upper support surface of an upper load lock support **567** and an upper support surface of a lower load lock support **568** of the second dual load lock **564**. Upper load lock support **567** and lower load lock support **568** can be disc-shaped pedestals, for example. In the depicted embodiment, the first vertical pitch P**1** is less than the second vertical pitch P**2** (i.e., $P1<P2$). In some embodiments, the second vertical pitch P**2** is approximately twice (2×) the first vertical pitch P**1** (i.e., $P2=2\times P2$). Furthermore, the vertical spacing V between the blades B**2** and B**3** can be equal to P**1** and the spacing between blades B**1** and B**3** can be equal to 2×V. By way of example, Pitch P**1** may be between about 7 mm and about 25 mm, or even about 10 mm and about 20 mm, for example.

As shown, the first dual load lock **562** is positioned above the second dual load lock **564**. However, it should be understood that the first dual load lock **562** and the second dual load lock **564** may be positioned alongside one another, i.e., in a side-by-side orientation wherein the first dual load lock **562** of pitch P**1** can be provided in load lock apparatus **409**A and the second dual load lock **564** of pitch P**2** can be provided in load lock apparatus **409**B, or vice versa. In another embodiment, the two first dual load locks **562** of pitch P**1** can be provided in load lock apparatus **409**A and two second dual load locks **564** of pitch P**2** can be provided in load lock apparatus **409**B, or vice versa.

As shown, the first dual load lock **562** is configured to receive the second blade B**2** and the third blade B**3**. The second dual load lock **564** of pitch P**2** is configured to receive the first blade B**1** and the third blade B**3**. Thus, in one aspect, a put and get sequence carried out by the robot apparatus **100** can be:

Get of two substrates **115** from lower load lock **564** by blades B**1** and B**3**,

Get by blade B**2** from a first process chamber **403**,

Put of substrate **115** by blade B**1** to same process chamber **403**,

Get by B**1** from another process chamber **403**,

Put by B**3** to the other process chamber **403**, and

Put in upper dual load lock **562** by blades B**2** and B**1**.

Other suitable sequences where blades B**1** and B**3** get from lower load lock **564** and put in upper load lock **562** are possible. For example, the following sequence could alternatively be employed:

Get of two substrates **115** from lower load lock **564** by blades B**1** and B**3**,

Get by blade B**2** from a first process chamber **403**,

Put of substrate **115** by blade B**3** to same process chamber **403**,

Get by B**3** from another process chamber **403**,

Put by B**1** to the other process chamber **403**, and

Put in upper dual load lock **562** by blades B**2** and B**3**.

The above two sequences may be effective reversed by starting with a get of two substrates **115** from upper load lock **564** with blades B**2** and B**3** (or blades B**1** and B**2**) and ending with a put of two substrates **115** to the lower load lock **564** with blades B**1** and B**3**.

In an additional embodiment, a robot apparatus **600** is provided wherein the first blade **116** includes dual end effectors B**1.1** and B**1.2** as shown in FIG. **6**A. The other two wrist members also include two end effectors each. Thus, the end effectors B**1.1** and B**1.2** move in unison as do the other pairs of end effectors. FIGS. **6**A and **6**B illustrates an embodiment including six end effectors. Each of the pairs of end effectors are independently rotatable. As shown in FIG. **6**B, the dual end effectors B**1.1** and B**1.2** are shown connected to the first wrist member **116** by orientation adjuster **628**. The same construction is used for dual end effectors B**2.1** and B**2.2** attached to second wrist member **118**, and the dual end effectors B**3.1** and B**3.2** attached to the third wrist member **120**. The drive motor assembly **105** and the blade drive assembly can be the same as described before for FIG. **1**A-**3**B. This embodiment enables even more Put and Get capability and thus enhanced efficiencies. As should be understood, in this embodiment, load lock apparatus will include twice as many substrate support locations per load lock. One suitable Put and Get sequence that can be carried out by robot apparatus **600** is, for example:

Dual GET from a load lock by B**1.1**, B**1.2** & B**2.1**, B**2.2** (4 substrates **115** picked up),

B**3.1** and B**3.2** carry no substrates initially,

Process chamber **403** GET by B**3.2**,

Process chamber **403** PUT by B**2.1**,

Process chamber **403** GET by B**3.1**,

Process chamber **403** PUT by B**2.2**,

Process chamber **403** GET by B**2.2**,

Process chamber **403** PUT by B**1.1**,

Process chamber **403** GET by B**2.1**,

Process chamber **403** PUT by B**1.2**, and

Dual PUT in the load lock (or another load lock) by B**2.1**, B**2.2** & B**3.1**, B**3.2** (4 substrates **115**).

Another possible sequence that can be carried out by the robot apparatus **600** is:

Dual GET from a first load lock by B**2.1**, B**2.2** & B**3.1**, B**3.2** (4 substrates **115** picked up),

B**1.1** and B**1.2** carry no substrates initially,

Process chamber **403** GET by B**1.2**,

Process chamber **403** PUT by B**2.1**,

Process chamber **403** GET by B**1.1**,

Process chamber **403** PUT by B**2.2**,

Process chamber **403** GET by B**1.2**,

Process chamber **403** PUT by B**3.1**,

Process chamber **403** GET by B**2.1**,

Process chamber **403** PUT by B**3.2**, and

Dual PUT in the first load lock (or another load lock) by B**1.1**, B**1.2** & B**2.1**, B**2.2** (4 substrates **115**).

With reference to FIG. **7**, a method **700** of transporting substrates within an electronic device manufacturing apparatus (e.g., electronic process device manufacturing apparatus **400**) is provided. The method **700** includes, in **702**, providing a mainframe (e.g., mainframe **401**) including a transfer chamber (e.g., transfer chamber **413**) and at least two process chambers (e.g., process chambers **403**). The method **700** further includes providing a first dual load lock (e.g., first dual load lock **562**) coupled to the mainframe and including a first vertical pitch (e.g., P**1**) between an upper load lock support (e.g., upper load lock support **565**) and a lower load lock support (e.g., lower load lock support **566**) of the dual first load lock, and a second dual load lock (e.g., second dual load lock **564**) coupled to the mainframe and including a second vertical pitch (e.g., P**2**) between an upper load lock support (e.g., upper load lock support **567**) and a lower load lock support (e.g., second load lock support **568**) of the second dual load lock, wherein the first vertical pitch is less than the second vertical pitch (e.g., P**1**<P**2**). In some embodiments P**2**=2×P**1**.

The method **700** further includes, in **706**, providing a robot apparatus (e.g., robot apparatus **100**) configured to transport substrates (substrates **115**) to the first dual load lock and the second dual load lock and the at least two process chambers, the robot apparatus including: an upper arm (e.g., upper arm **102**) including an inboard end (e.g., inboard end **102***i*) and an outboard end (e.g., outboard end **102***o*), the inboard end configured to rotate about a shoulder axis (e.g., shoulder axis **104**), a first blade (e.g., first blade B**1**) configured for independent rotation relative to the upper arm about an outboard axis (e.g., outboard axis **107**), the first blade including a first end effector (e.g., first end effector **122**), a second blade (e.g., second blade B**2**) configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector (e.g., second end effector **124**), and a third blade (e.g., third blade B**3**) configured for independent rotation relative to the upper arm about the outboard axis, the third blade including a third end effector (e.g., third end effector **126**).

The method **700** further includes, in **708**, servicing the first dual load lock (e.g., first dual load lock **562**) with the second blade B**2** and the third blade B**3** (or optionally with the with the first blade B**1** and the second blade B**2**); and in

710, servicing the second dual load lock (e.g., second dual load lock 564) with the first blade B1 and the third blade B3.

In the case of the FIG. 6 embodiment with end effectors B1.1 through B3.2, a first load lock can be serviced with end effectors B2.1 and B2.2 and end effectors B3.1 and B3.2, or optionally end effectors B1.1 and B1.2 and end effectors B2.1 and B2.2.

The foregoing description discloses only certain example embodiments. Modifications of the above-disclosed systems, apparatus, and methods which fall within the scope of the disclosure will be readily apparent to those of ordinary skill in the art. Accordingly, while the present disclosure has been disclosed in connection with certain example embodiments, it should be understood that other embodiments may fall within the scope of the invention, as defined by the following claims.

The invention claimed is:

1. A robot apparatus, comprising:
- a drive motor assembly;
- an upper arm configured to rotate relative to the drive motor assembly, the upper arm including an inboard end and an outboard end, wherein the inboard end is configured to rotate about a shoulder axis;
- a first blade configured for independent rotation relative to the upper arm about an outboard axis, the first blade including a first end effector;
- a second blade configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector and;
- an inboard drive assembly coupled to the drive motor assembly, the inboard drive assembly comprising:
  - a first inboard pilot;
  - a first driving pulley mounted for rotation on the first inboard pilot and configured to facilitate the independent rotation of the first blade relative to the upper arm about the outboard axis; and
  - a second driving pulley mounted for rotation on the first driving pulley and configured to facilitate the independent rotation of the second blade relative to the upper arm about the outboard axis.

2. The robot apparatus of claim 1, wherein the drive motor assembly includes:
- an upper arm drive motor configured to cause the independent rotation of the upper arm;
- a first drive motor configured to cause the independent rotation of the first blade; and
- a second drive motor configured to cause the independent rotation of the second blade.

3. The robot apparatus of claim 1, wherein the drive motor assembly includes an upper arm shaft, a first blade shaft, and a second blade shaft, wherein the upper arm shaft, the first blade shaft and the second blade shaft are co-axial.

4. The robot apparatus of claim 3, wherein the first driving pulley is coupled to the first blade shaft and the second driving pulley is coupled to the second blade shaft.

5. The robot apparatus of claim 1, wherein the first end effector and the second end effector lie one above another when configured in a folded and zeroed configuration.

6. The robot apparatus of claim 1, wherein a first length L1 from the shoulder axis to the outboard axis and a second length L2 between the outboard axis and a substrate support center of the each of the first end effector and second end effector is related by L2>L1.

7. The robot apparatus of claim 6 wherein L1≤L2≤2L1.

8. The robot apparatus of claim 6 wherein 1.5L1≤L2≤2L1.

9. The robot apparatus of claim 1, wherein the inboard drive assembly is configured at the inboard end of the upper arm, and wherein the inboard drive assembly further comprises:
- a second inboard pilot, wherein the second driving pulley is further mounted for rotation on the second inboard pilot.

10. The robot apparatus of claim 1, comprising an outboard drive assembly, having:
- a first outboard pilot;
- a first driven pulley mounted for rotation on the first outboard pilot; and
- a second driven pulley mounted for rotation on the first driven pulley.

11. The robot apparatus of claim 1, wherein the outboard end of the upper arm comprises:
- a first outboard pilot;
- a second outboard pilot;
- a first driven pulley mounted for rotation on the first outboard pilot; and
- a second driven pulley mounted for rotation on the second outboard pilot.

12. The robot apparatus of claim 1, wherein the first blade includes dual end effectors.

13. The robot apparatus of claim 1, further comprising:
- a third blade configured for independent rotation relative to the upper arm about the outboard axis, the third blade including a third end effector.

14. An electronic device manufacturing apparatus, comprising:
- a mainframe including a transfer chamber and at least two process chambers;
- a first dual load lock coupled to the mainframe and including a first vertical pitch between an upper load lock support and a lower load lock support;
- a second dual load lock coupled to the mainframe and including a second vertical pitch between an upper load lock support and a lower load lock support of the second dual load lock, wherein the first vertical pitch is less than the second vertical pitch; and
- a robot apparatus configured to transport substrates to the first dual load lock and the second dual load lock and the at least two process chambers, the robot apparatus including:
  - an upper arm including an inboard end and an outboard end, the inboard end configured to rotate about a shoulder axis,
  - a first blade configured for independent rotation relative to the upper arm about an outboard axis, the first blade including a first end effector,
  - a second blade configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector, and
  - a third blade configured for independent rotation relative to the upper arm about the outboard axis, the third blade including a third end effector,
  - wherein a vertical spacing between the first end effector and the second end effector equals the first vertical pitch and a spacing between the first end effector and the third end effector is equal to the second vertical pitch.

15. The electronic device manufacturing apparatus of claim 14, wherein the second vertical pitch is approximately twice the first vertical pitch.

16. The electronic device manufacturing apparatus of claim 14, wherein the first dual load lock is positioned above the second dual load lock.

17. The electronic device manufacturing apparatus of claim **14**, wherein the second dual load lock is configured to receive the first blade and the third blade.

18. The electronic device manufacturing apparatus of claim **14**, wherein the first dual load lock is configured to receive the first blade and the second blade or the second blade and the third blade.

19. The electronic device manufacturing apparatus of claim **14**, wherein the first blade and third blade are spaced to put and get substrates to and from the upper load lock support and the lower load lock support of the second dual load lock.

20. The electronic device manufacturing apparatus of claim **14**, wherein the second blade and the third blade and the first blade and the second blade are spaced to put and get substrates to and from an upper load lock support and a lower load lock support of the first dual load lock.

21. A robot apparatus, comprising:

a drive motor assembly;

an upper arm configured to rotate relative to the drive motor assembly, the upper arm including an inboard end and an outboard end, wherein the inboard end is configured to rotate about a shoulder axis;

a first blade configured for independent rotation relative to the upper arm about an outboard axis, the first blade including a first end effector;

a second blade configured for independent rotation relative to the upper arm about the outboard axis, the second blade including a second end effector; and

an outboard drive assembly coupled to the drive motor assembly, the outboard drive assembly comprising:

a first outboard pilot;

a first driven pulley mounted for rotation on the first outboard pilot and configured to facilitate the independent rotation of the first blade relative to the upper arm about the outboard axis; and

a second driven pulley mounted for rotation on the first driven pulley and configured to facilitate the independent rotation of the second blade relative to the upper arm about the outboard axis.

* * * * *